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Quantum pseudo-weirdness: Disentangling myth from reality.

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Abstract

A model fully compatible with quantum field theory was constructed in [1] from first principles explicitly in accordance with objectivity and local realism. Energy-momentum quantization emerges there because of densely spread phase singularities rooted in a chaotic background, which otherwise bears all required symmetries. Besides, bringing together duality and relativity was shown to entail the violation of Bell's inequalities, namely the oscillatory nature of elementary objects, the information content of which is preserved during transport by conservation law.

In the present letter, the duality constraint is relaxed to bring focus on the peculiar wave function collapse of state superposition. Possibly its most salient manifestation lies in "non-local entanglement." Coming from mainstream Copenhagen interpretation of quantum mechanics, it is claimed to have been experimentally verified in numerous variants through Bell, Clauser, Horne, Shimony and Holt's inequality criterion.

Unfortunately, as we demonstrate, it is wrongly derived because of an original logical confusion, strangely remained unnoticed so far, mixing up a particular case with the general case doubled with unphysical hypotheses.

Consequently, it is now clear that the true nature of quantum mechanics is the statistical description of a "vacuum" oscillatory excitations abiding by the laws of classical mechanics.

"*The more cheese there is, the more holes there are. But the more holes there are, the less cheese there is. So the more cheese, the less cheese!*"

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INTRODUCTION ON LOCALITY

Locality is one of the founding principles of mechanics, which states that information propagates gradually throughout time and space. One might reformulate that in common language as bit by bit and step by step but at the expanse of its own limitations, since the better way is to invoke relativity. More specifically, it implies that an object can be affected by another one causally only through a mediator. Claiming that this principle may be circumvented in specific instances requires utmost attention, following Occam's razor and because it may undermine the whole edifice. Newton was put off by his own theory of gravitation for this very reason by "spooky action at a distance". Einstein, Podolsky, Rosen, Schrödinger, de Broglie and Bohm, to name only a few historical prominent figures, were also put off by the Copenhagen interpretation for a similar reason [2].

They asked: What can be so different from the laws of local mechanics, with these experiments of quantum entanglement supposed to challenge them, to the point that we can give some credit to nonlocality while, at the same time, continuing to hold true their foundation even otherwise verified in all other cases? In mainstream language, a standard Stern and Gerlach or a polarizer measurement is understood as a collapse of the wave function from a superposition of pure states down to only one of the allowed basis states. Classically though, one would speak of the uncertainty about initial conditions.

To put things clearly into perspective, let us take a pair of physical objects, call them 'a' and 'b'. Let us further imagine that we have prepared them in an experiment initially to be correlated. We then perform measurements A on 'a' and B on 'b'. Initially at time $t = 0$, by hypothesis, the joint probability of A(a) and B(b) is not separable:

$$P\left(A(a), B(b)|t=0\right) \;=\; P\left(A(a)\right) P\left(B(b)|A(a), t=0\right) \neq P\left(A(a)\right) P\left(B(b)\right). \qquad (1)$$

Now, locality simply means physically that evolving this system dynamically through time also affects the joint probability dynamically. Mutual information stored initially between 'a' and 'b' may gradually dissipate in a finite amount of time according to some irreversible kinetics, for example because of uncontrolled interactions of 'a' and 'b' with a heat bath, in which case the probability converges to an equilibrium probability P_{eq} independent of the initial condition. Such a process would typically be described by a Markovian master

equation of the type:

$$\frac{\partial}{\partial t}P\left(B(b_i),t|A(a),t=0\right)=\sum_{f\neq i}\left\{\mathbf{T}_{i,f}\ P\left(B(b_f),t|A(a),t=0\right)\ -\ \mathbf{T}_{f,i}\ P\left(B(b_i),t|A(a),t=0\right)\right\}, \tag{2}$$

where $T_{i,f}$ models a transition probability rate from state b_i to state b_f with, $\forall i,\ \sum_f \mathbf{T}_{i,f}=0$ and detailed balance $\mathbf{T}_{i,f}P_{eq}(B(b_f))=\mathbf{T}_{f,i}P_{eq}(B(b_i))$. Quantum mechanically, the same is true for the density matrix, which is coined a decoherence process as one started from the wave function, which makes more explicit the possibility of phase interferences in the initial results. During the process, interferences blur out ending up disappearing when equilibrium is reached. In our binary examples, the transition probability rate is one half.

But, mutual information can also remain stationary, for instance via energy-momentum conservation and relativity if the system 'a' and 'b' remains isolated and non radiating, in which cases one simply has:

$$P\left(A(a),B(b)|t>0\right)=P\left(A(a),B(b)|t=0\right). \tag{3}$$

For the illustration, if 'a' and 'b' are the angular momenta of a photon pair, both being localized energy quanta, abstracted as dual point particles, and both being given an initial thrust as they become correlated, as it happens in spontaneous parametric down conversion for example, conservation and relativity guarantee that each one of them carries on in the same state as initially. This remains true until each member of the pair is perturbed in the experiment measuring 'a' with A and 'b' with B. It is blatantly clear that spatial information is irrelevant (or any other information about a parametrisable space which remains independent of the measurement contexts), placing measurement A anywhere in space, say x_A, and B in x_B does not change the fact that eq.(3) remains true:

$$P\left(A(a),B(b)|t>0\ ;\ x_A\neq 0,\ x_B\neq 0\right)=P\left(A(a),B(b)|t=0\ ;\ x_A=0=x_B\right). \tag{4}$$

Because both photons are dual particles, they bear the information about the initial condition within their phase, as was reminded in [1], therefore results at (t_A,x_A) and (t_B,x_B) exhibit interference patterns in the form of cosine correlations.

Quantum entanglement experiments are designed to deal with this kind of setup, repeating a large number of such measurements in order to assess the empirical joint probability of measurements A and B: $P\left(A,B|t_A,t_B;x_A,x_B\right)$. Despite this, they have been put forward

for almost sixty years to have allegedly exposed a fundamental difference with the law of locality, which states that our lack of knowledge about the initial conditions lead to a probabilistic description, here expressed in the spatio-temporal form eq.(4). Of course, classically, internal states may oscillate or "breath", spin may precess for example along each particle path, but the previous sentence remains true as long as there is a law of conservation for the pair of internal states, such as total angular momentum. Let us now set out the argument and go through it to identify the mistake and conclude.

BELL & CLAUSER HORNE SHIMONY HOLT'S PARALOGISM

A. The basic formulation

Let us formulate the problem mathematically as the initial drawing of pairs of random variables (a, b), which are sent to A and B, where each apparatus is set according to some parameter m_A and m_B. The model has joint law: $P\left(A(a, m_A),\ B(b, m_B)\right)$. Mimicking spin one or one-half measurements, parameters m_A and m_B are further set to take two values each $m_{1,2}$, corresponding for instance to two different angles of a polariser or two directions in a Stern and Gerlach. By definition, results take two values as well: $A(a, m_A) = \pm 1$ and $B(b, m_B) = \pm 1$, which fact corresponds in our example to the physics of the polarization of light crossing both polarisers.

Bell, in [3], imposes a separability condition:

$$P\left(A(a, m_A),\ B(b, m_B)|\lambda\right) = P\left(A(a, m_A)|\lambda\right) P\left(B(b, m_B)|\lambda\right), \tag{5}$$

with λ modelling a hidden state variable. Eq.(5) stems from the assumed independence of the pair measurement results upon each other's value and context, that Bell coins the name "local realism". In this regard, extending Bell's first proposition, the test proposed by the authors of [4] computes four cross-correlation points assembled in the following formula leading to an inequality:

$$\begin{aligned} &\| E\left(A(a, m_1)B(b, m_1) - A(a, m_1)B(b, m_2) + A(a, m_2)B(b, m_1) + A(a, m_2)B(b, m_2)\right) \| \\ &= \| E\left(A(a, m_1)\left(B(b, m_1) - B(b, m_2)\right) + A(a, m_2)\left(B(b, m_1) + B(b, m_2)\right)\right) \| \leq\ 2, \end{aligned} \tag{6}$$

since when the difference $\left(B(b, m_1) \pm B(b, m_2)\right) \in \{0, 2\}$ is 2 then the sum is 0 and vice versa, where $E(\cdot)$ is the expectation value performed over the unknown distribution of λ.

However the premise eq.(5) is simply incompatible with the other assumption, which is supposed to be verified altogether, that a and b are correlated via λ. If (a, b) is a pair of correlated variables initially, its joint measurement probability distribution is non separable and remains so, in space and through time, as long as no measurement is performed either on a or b, as we recall in the introduction, eq.(4). Let us now be more explicit for even more clarity.

B. The blunder

So Bell wished to give an experimentally verifiable test of the EPR paradox, that would outline a fundamental difference between classically correlated variables and quantum correlated (entangled) ones. In so doing, he modelled locality and realism as eq.(5), which can also be explicitly written for the previous experiments as the mutual independence of measurements. Therefore, we have that:

- The conditional probability of each measurement is independent on the other's context and result:

$$P\left(A(a, m_A)|B(b, m_B),\ \lambda\right) = P\left(A(a, m_A)|\ \lambda\right). \tag{7}$$

This is clearly true for any other subsequent measurement with A, right after $t > t_A$ the first interaction process with the apparatus, because of decoherence eq.(2) towards an equilibrium state $a_{t>t_A}$ now independent of b.

Bell referred to the various couple of contexts (m_j, m_k) $((j, k) \in \{1, 2\}^2)$ independently, they can in fact be mapped advantageously as in a bijective indexation $(j, k) \to i \in [\![1, 4]\!]$. So let us take our pair measurements $(A(a, m_j), B(b, m_k)) \in \{-1, 1\}^2$, over the set of which the lexicographic order is total, which means that their Hilbert orthonormal basis vectors can be compared: $(-1, -1) < (-1, 1) < (1, -1) < (1, 1)$. Their product average (their correlation when $A(a, m_j)$ or $B(b, m_k)$ are centred) is: $\forall (j, k) \in [\![1, 2]\!]$, $\overline{A_j B_k} \in [-1, 1]$ and is estimated empirically over this dictionary, where the overline denotes now the empirical average over the experimentally achievable set of λ. Repeating to be clear, the various contexts $\in \{m_j, m_k\} \to \in \{m_i\}$ may result in various probability distributions, therefore various cross-correlation points: $\overline{A_j B_k} \equiv \overline{AB}_i$.

Bell claims in [3] that because (the reader may please refer to eq.(16) in [3]):

$$\exists\,(A,B)\ni\|\overline{AB}+AB\|>0, \tag{8}$$

quantum mechanical correlations could not be approximated by hidden state variables. The original demonstration steps are cumbersome and the form 8 shows already how wrong and tautological the starting point is, in addition to saying nothing new about the underlying physical system. The mistake is done between eq.(21) and eq.(22) in [3] where the independent draws of pairs of variables are mixed up in the unauthorized factorization as was done in eq.(6):

$$\overline{AB\pm AB'}=\overline{A\,(B\pm B')}. \tag{9}$$

In fact, the unwanted slight of hands and the catch for the paralogism, is that this is true for fixed context only, or for complete independence eq.(5), and obviously becomes wrong for a tunable context and modifiable correlations:

$$\overline{AB}_1\pm\overline{AB}_2\neq\overline{A_{j_1,j_2}\,(B_{k_1}\pm B_{k_2})}. \tag{10}$$

In other words, as it seems obvious, making use of a particular case to derive a formula cannot help obtain the general case. Again, let us insist for clarity, this is forbidden because, even if m_A is set in fixed position m_j in both experiments, the fact that (a,b) is correlated initially and remains so (e.g. via their phase for photon pairs), imposes at least taking account of a new context when m_k is modified:

$$P\,(A(a,m_j)|B(b,m_k),\ \lambda)=P\,(A(a,(m_j,m_k)\equiv m_i)|\ \lambda)\,, \tag{11}$$

but for a given context m_i written in identical form at both ends of the experiment with parameter notation $(m_j,m_k)\rightarrow m_i$, a and b being correlated, we necessarily have:

$$P\,(A(a,m_j)|B(b,m_k),\ \lambda)=P\,(A(a,m_i)|B(b,m_i)\ \lambda)\,, \tag{12}$$

which simply cancels Bell's non-physically motivated premise eq.(5).

Clauser Horne Shimony Holt make the same mistake trying in deriving eq.(6) (eq.(1a) in [4]), again the logical confusion with predicates and quantification also taking a particular case as being general under the averaging integral before eq.(1a), thus claiming as in eq.(6) that:

$$\mathbf{E}\equiv\|\overline{AB}_1-\overline{AB}_2+\overline{AB}_3+\overline{AB}_4\|\leq 2. \tag{13}$$

Their demonstration steps being similarly cumbersome, because of the non-physically motivated presumption, mixes up A_j and B_k, but it is evident that eq.(13) is wrong because the true bound is:

$$\mathbf{E} \leq 4. \tag{14}$$

We incidentally see that the quantum mechanical bound $2\sqrt{2}$ is far from showing optimally correlated pairs of variables, with respect to this formula.

Let us yet further underline the inconsistency of the "would-be" bound of value 2, since it is attained for correlated variables with the following joint probabilities:

$$P_{A+,B+} = P_{A-,B-} = \frac{3}{4}, \tag{15}$$

in setups $i = (1, 3, 4)$ and

$$P_{A+,B-} = P_{A-,B+} = \frac{3}{4} \tag{16}$$

in setup $i = 2$. Those correlations of course already imply a violation of Bell's unreasonable "local realism" assumptions eq.(7). As was outlined above and as it seems now completely obvious, his premise simply cannot be compatible with correlated variables. The true upper bound nonetheless is attained when A and B are perfectly correlated in setups $i = (1, 3, 4)$ and perfectly anti-correlated in setup $i = 2$. For illustration purposes, with A and B unbiased, take $\overline{AB}(m_i) = \frac{1}{2}\left(1 - \mathrm{sign}\left(m_i - 2\right)\right)$ and setup parameters are $m_{1,3,4} = 1$ and $m_2 = 3$. Another correlation function $\overline{AB}(m_i) = \frac{1}{2}\left(1 - \tanh(4m_i - 8)\right)$ yet would approach the true upper bound within two digits with the same parameter setup.

In that sense, translation invariance in context space is important for proper mapping $(j, k) \rightarrow i$. The value $\mathbf{E}$ may inform on a degree of pairwise "entanglement" and the criterion further requires the correlation function to oscillate at fixed wavelength in context space. In that sense, atom positions in a crystal at zero temperature are not entangled, but become more and more so as temperature increases. A regular fluid in fact, like a Lennard-Jones fluid model, already shows some degree of entanglement: The radial density of both (the pair correlation function of particles) exhibit regularly oscillating positive and negative correlations locally with some spatial extent.

CONCLUSION

While writing [1], it was astounding to realise that statistical entanglement had been devised already almost thirty years ago by Spreeuw with classical optics [5] which has been experimentally validated since [6, 7], but also in Brownian motions [8, 9] and with droplet walkers [10] more recently by Papatryfonos, Bush and their coworkers [11, 12]. In all situations, the quantum mechanical results are identically obtained: How can the same mathematics and the same results lead to two interpretations at odds with each other? In fact, while writing this letter, one of us found two notes that have unfortunately remained unreported and unquoted but whose authors, Canals-Frau and Perdijon, are entirely right [13, 14]. As a matter of fact, we just rediscovered what they already had revealed more than thirty years ago!

Here we have highlighted an error in the initial claimed proof supporting the Copenhagen postulates, which should easily succeed in convincing the mainstream reluctance to move forward at last. Specifically, the combination of various contexts was left aside in its derivation concomitantly to being wrongly later reintroduced as tests are being performed. This forced-in paralogism stems from Bell's proposal of a model of local realism which should have implied that pair measurements are made independent of contexts and outcomes, as if already at thermal equilibrium, leading to the separability of the joint probability. However, on the one hand, this modelling is unphysical because relativity is a first principle that guarantees the conservation of mutual information via transportation through time in space, thus if objects are correlated initially they remain so until they further interact independently with their environment. On the other hand, the derived inequality criterion is even inconsistent in simply getting at a particular threshold for correlated random variables, because there exists a wide range of such correlated variable pairs both breaking Bell's probabilistic premise and verifying the criterion nonetheless. The formula on the l.h.s. of eq.(13), though, might give partial insight about the degree of "entanglement," becoming a notion about a specific type of cross-correlation. Quantum mechanical bodies are not even optimally entangled. Thus, so-called "nonlocality" is at the very best a reduced reformulation of the conservation of cross-correlations between moving bodies: These may be astutely set-upped initially to be either correlated or anti-correlated with a fixed wavelength and according to context, before later being measured independently.

With [1] and this letter, it becomes obvious that the poor cat is either dead or alive, not both at the same time, as Schrödinger pointed out in awe about one century ago. Consequently, decoherence is really the process by which an ensemble of interacting elementary bodies, or wave packets, lead to probabilities because of our lack of detailed knowledge. There is no such thing as a wave function collapse because one is dealing with statistical ensembles. The postulates of quantum mechanics were wrong indeed as some have been claiming all along like Penrose. So-called nonlocality, superposition of states and wave function collapse were unfounded mystifications based on false evidence. State superposition may only be defined statistically and correlations may be conveyed via conservation and transport. Let us mention Young's slit experiment and many other quantum-typical tests successfully passed by droplet walkers [11, 12, 16–24]. The quantum arsenal is a formal one which serves the calculations of statistical properties of oscillatory excitations being evolved unitarily, as was hinted at by Jaynes [15] and extensively explored by Khrennikov [25]. However, without modifications, it cannot give accurately access to nonlinear evolutions of different types of excitations and stronger correlations. In that respect, Born rule which states that: $P(m_i) = \|\Psi \cdot M_i\|^2$, where Ψ is the wave function vector, m_i is some context with its associated basis vector M_i, is a kind of accident and can be changed to accommodate different view points on dynamical systems. Mathematically and physically, no particular reason was ever given to explain this privileged frame of choosing the canonical scalar product with norm two to compute probability measures and not any other energy preserving projection or, in retrospect, added priors. An explicit probabilistic construction making use of wavelet projections, over the fluctuations of a medium, was given in [1], starting with the stochastic integration: $\rho(t) = e^{i\int_0^t \mathrm{d}s\,\omega(s)}\rho(0)$, where ρ is a medium quantity of interest and ω is a complex random evolution operator. It suggested indeed that the projection basis is somewhat arbitrary and left to the discretion of the experimenter according to their specific needs. In fact, it was argued with examples from reaction-diffusion systems that quantum mechanics and field theory are a linear approximation of nonlinear microscopic complex kinetics. Working with a medium avoids dealing with over abstractions as point-like particles. Such an abstraction is justified if dealing with the centre of mass but it is already less so if dealing with the internal symmetries of currents giving rise to the overarching topological structure that mimics a particle. In that regard, string-like particles are no much better justified abstraction. This work suggested avenues to explore generalizations of the standard

tools at hand taken from quantum field theories, that could borrow more adapted tools from the fields of disordered systems. In the same spirit Khrennikov already introduced generalized probabilistic theory [26].

The extremely simple correction of the original mistake presented here, through a domino effect nonetheless, has huge consequences in the many theoretical fields labelled as "quantum" that must be relabelled as "statistical". Not only does it put an end to untestable and extremely unphysical interpretations such as Everett's multi-worlds or reflections about the limits of knowledge in the epistemology of nonlocality, but also quantum computing, quantum teleportation, quantum cryptography and so on, are obsolete nonsense in their most unreasonable claims relying on nonlocality and state superposition such as supremacy, unconditional security to eavesdropping, no-cloning state transfer, etc. In fact, e.g. quantum supremacy at its core would have violated the second law of thermodynamics which stipulates, through Landauer's limit, that N Q-bits, that is 2^N classical bits of information, cost at least $N\kappa T \ln(2)$ of heat dissipation to be manipulated. We must speak at best of N statistical bits and there is no easy way around for any system close to thermal equilibrium. Similarly, eavesdropping on a particular state and its cloning is not at all protected by statistical states.

Therefore, in quantum mechanics, the only important word is "quantum." We know since the advent of the mathematics of the Hilbert space, that quanta of energy may arise because of the wavy nature of fundamental solutions on compact spaces. The analogy between quantum field theory and statistical field theory was established early on, and if any mathematical tool applies to both equivalently, that's because the former is a particular subfield of the latter: Every known phenomenon, ranging from supra-conductivity to P-N junctions, tunneling or quantum dots, nuclear decay or yet quark confinement, etc. must be due to statistical fluctuations and be described as such, as they are in fact already. Nonetheless, the recent flurry of quantum "analogs" [22] now must be upgraded to the status of quantum models, in other words, models of the unknown microscopic description of vacua. In addition, interestingly, quantum gravity is no longer a problem, it is just gravitation as an emerging field, the geometry of which might fluctuate indeed but not in state superposition. It is no longer surprising that Einstein equations have the aspect of fluid equations. One could thus speculate on how to grasp the equivalence principle as an emerging fact. But this was already understood in the thermodynamic approach by Jacobson

[27], stipulating that Einstein equations are an equation of state. The underlying statistical wave mechanics that one has still to explore is nonetheless certainly going to further affect our understanding of anomalies, like Tully-Fisher's, and maybe more in cosmology. Of more down-to-earth and practical consequence, nuclear fusion and Landau scattering can interfere [28]: If Landau scattering dominates, nuclear fusion is hampered, a fact which is never outlined because of conceptual misunderstanding about Landau damping [29, 30]. In hot plasmas, fusion process in the bulk looks like a phase transition, as Debye's screening length shortens with increasing density to reach de Broglie's thermal wavelength scale, and at high enough temperatures. It is noteworthy to remark that in the core of common stars the plasma state has crossed from classical over to quantum and from collisionless over to strongly coupled. It is also a region where, in fact, quantum coupling between fermions is no longer negligible, that is, where the plasmon quantum of energy is comparable to Fermi's energy. This strongly casts doubts on the ongoing efforts, based on the equilibrium so-called Lawson's criterion, to achieve controlled magnetic fusion as designed in tokamaks, where plasmas are 'ideal,' that is at very low density and in which Landau scattering thus, indeed, dominates. However, focusing our attention on the subtleties of the phase transition could inspire new conceptions.

Philosophically, the whole of physicists were up to now in a heretical state in the etymological sense of cleaved, maybe "schizophrenic" in some individuals, but not in superposition: realists and Copenhagenists. Notions such as "epistemic" or "ontic" have often been invoked, but as it is clear and indisputable now, there is no room for interpretation. In retrospect, how could we have tolerated the coexistence of realism and anti-realism without losing critical reason? While Bell tried to offer a model of locality to solve the EPR paradox, on the one hand, first principles need not be modelled because they precede modelling, on the other hand, Bell made a big mistake, reproduced by Clauser Horn Shimony Holt and all others who have worked in the related research areas for not having checked appropriately. The community of physicists, a process that probably takes root and nucelates during studies, was divided into two separate phases: those who wanted to believe in state superposition, because it is magical, and chose to work on its consequences; and the one made up of those who felt instinctively bad about it and chose to devote their time to other subjects while placing their trust (not without defiance) in the first group for their shared seriousness. At any rate, it is a good subject of research in the field of socio-psychology. Canals-Frau anal-

ysed more than thirty years ago that possibly the peer-review mechanism was involved in this state of group inertia as, quoting : "D'où une paupérisation de la littérature physique, privée de la stimulation de toute mise en cause. Le progrès de la vraie théorie physique a eté barré pendant des années par de tels errements."

To wrap it up, the Copenhagen interpretation tried to accommodate causality with nonlocal state superposition, unknowable by essence, and unaccounted for wave function collapse, but it made things worse for the foundations. If it remains objectionable to imagine that the world might bear some kind of nonlocal finality just as a wave influences for a relative time the fate of a particle, for instance, their joint state is not experimentally unknowable by essence. Current science has very little to say about non objectifiable phenomena, even discussing emerging structures such as DNA as being a manifestation of hidden information, but it certainly can state that within a reduced frame of empirical observations, its goal is to completely describe the material world. Since Bacon and Descartes, the task of science does not consist in remaining idle spectators in front of the mysteries and beauties of the world, especially when the alleged mysteries are based on a forgivable error of calculation.

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